Charging of Company Fleets – power requirement and flexibility

based on the mapping of conventional-car usage to BEVs

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The paper analyzes driving distances of company cars and idle-times in the company yard in order to determine the requirements for the charging infrastructure for a company fleet at its home base. For this purpose, driving distances of conventional cars are mapped according to the type of car to an amount of electrical energy required for the elapsed tour, assuming those conventional cars are replaced by BEVs.

As a result 89% of all 6300 tours analyzed would have been possible with BEVs available on the market today without intermediate charging. In fact 70% of all tours require less than a third of the energy content of the vehicle battery. Comparing the required energy of the previous tour with the idle time of the vehicles after the tour in the company yard, 85 % of the vehicles need 11 kW or less per vehicle to recharge. In fact 70% of the vehicles can be recharged with 3.7 kW or less during idle time.

Keywords- battery electric vehicle (BEV); economic sectors, company cars; fleets, charging power; flexibility; distribution of daily driving distance; load shifting potential

I. INTRODUCTION

The energy revolution has reached the traffic sector and the boom in e-mobility has already started. Its relevance for climate protection can be determined by a significantly shorter CO_2 amortization time for battery electric vehicles (BEVs) than for vehicles with internal combustion engine (ICE) [1].

Currently, mainly private individuals own BEVs using their private charging infrastructure. According to German statistics, the average person drives not more than 40 km per day, which is mainly due to a large number of commuters [2]. Numerous studies on grid integration of BEVs are therefore investigating the transfer of current traffic statistics to e-mobility. Grid load has already been considered for many cases. This includes the comparison of commuters in various countries [3], locations such as a car parks with commercial, short and/or long-term parkers [4] or residential areas in cites [5] [6] [7]. Those as well as most studies consider only private users. According to the recent meta study of the Network Technology/Network Operation Forum (FNN) at VDE there is a lack of research in rural and commercial areas [8].

However, new registrations of passenger cars are largely in the economic sector (64,4 % in 2017) instead of the private sector [9]. For further dissemination of electric vehicles, the usability of BEVs in the economic sector is therefore essential. Hence, it is necessary to determine the utilization of BEVs in economic sectors and their resulting impacts on the local grid at commercial areas. Simultaneous and unregulated recharging may result in critical power peaks, for instance during lunch break or in the evening, as shown in [10].

This paper analyses the potential for the usability of BEVs in the commercial sector, expanding on [11] and [12]. Monitoring data from company cars are used to determine how many business trips could be made with BEVs within the different economic sectors. Furthermore, the charging requirements in terms of time and charging power are investigated. Finally, we consider the time flexibility of the charging events.

II. SYSTEM DESCRIPTION

The following section describes how the analysis is done to determine whether battery electric vehicles (BEVs) could be used within different economic sectors. Statistics of monitored driving profiles of company cars with internal combustion engines (ICEs) are used and then transferred to BEVs. The following section explains the database and assumptions used, including driving distances and clustering of single journeys to round trips, as well as idle time of the company cars after their return to the company yard and mapping of ICEs to BEVs available on the market today.

A. Comercial vehicles of different economic sectors

A collection of driving profiles of company cars within different economic sectors is used as database. The economic sectors are listed in TABLE *I*. The driving profiles were monitored over the period between 2011 and 2015 as part of the innovation cluster ‘regional eco mobility (2030 (REM2030) [13]. The data contains vehicle class, economic sector of every car, as well as every journey´s start and arrival time, driving distance and radius of travel around the home base. In total the database contains over 86.000 single journeys spread over almost 180 companies. The monitored company cars consists mostly of the vehicle class ‘medium

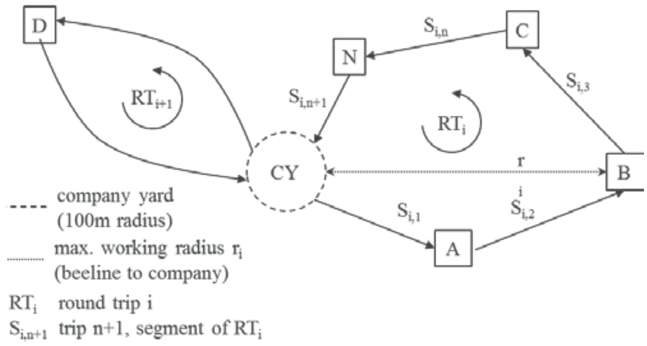

Figure 1. Clustering of single journeys to round trips, starting and ending within the company yard. Between round trips are parking times enabling the BEVs to be recharged.

cars' (38 %), followed by 'small cars' (25 %), 'transporters' (24 %) and 'executive cars' (12 %). The remaining journeys with heavy or special vehicles are not part of the following analysis.

Consecutive journeys of a single vehicle are added up into round-trips starting and finally returning to the company (Figure 1). Start and end time of a round trip is marked by its first journey and last journey. The driven distances are added up to the overall driving distance of the round trip, while the working radius is the maximum beeline between the company and each intermediate stop of a round trip. The company yard, where recharging can take place, is assumed to have a radius of 100 m in order to reduce deviations in the data and to include also tours ending near the company. For plausibility reasons, tours are excluded if the average speed of one of its individual journeys is not between 5 km/h and 130 km/h. Tours are not limited to one day.

To transfer the driving profiles from ICEs to BEVs a charging pattern is mandatory. As charging points and their accessibility cannot be taken for granted at the different destinations, it is assumed that charging only takes place at the company itself. The BEVs are charged at every stop at the company, except for short intermediate stops between two round trips with a parking time less than 1 h. This restriction is made on the assumption that the purpose of intermediate stops might be reorganizing (unloading and reloading items and/or change of users) the vehicle for the next destination without idle time at the charging station. The trips previous and following a stop of less than 1 h are considered part of an extended round trip without the option to recharge. In some cases this assumption leads to insufficient energy content in the battery to cover the second part of the extended tour or to insufficient parking time to fully recharge the battery with a given power rating after the end of the tour.

The resulting number of 6300 tours differ widely over the economic sectors as shown in Figure 2. Of those, the sectors D, E, K, M and L contribute less than 6% of all tours. The absolute number of tours covered in the survey for those sectors is too small to be considered representative and is not analyzed in more detail. The manufacturing sector, sector C, contains more than 20 % of all tours. All vehicle classes appear in the tours of sector C. This paper will show results for sector C in more detail. The key results will be shown for

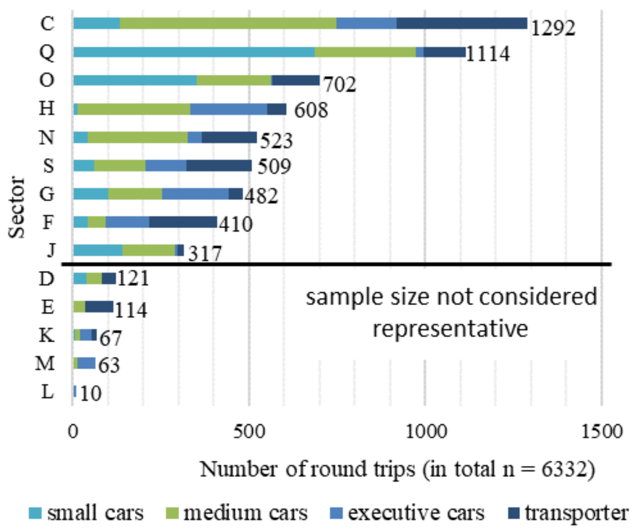

Figure 2. Total Number of round trips for each sector split into the used vehicles classes

all sectors except for the above-mentioned sectors with small database. The sectors and the applied indexes refer to the classification of economic sectors of the EU and are listed in TABLE *I*.

B. Battery electric vehicles (BEVS) and Charging infrastructure

As the above described driving profiles will be transferred from ICEs to BEVs, the following section deals with the assumptions regarding BEVs and charging infrastructure.

The available BEVs in Germany are assigned to the vehicle classes, taking the stock statistic of BEVs in January 2018 of the Federal Motor Transport Authority into account [14]. Furthermore, an average consumption (18.5 to 24 kWh/100 km) depending on the vehicle class is calculated by using the distribution of BEV registrations and their real consumption corresponding to ADAC EcoTests [15]. The battery capacity for each vehicle class is again determined based on the stock of cars in January 2018 and varies between 28 and 92 kWh. The numbers for each vehicle class are shown in TABLE *III*.

TABLE I. AVERAGE CHARACTERISTICS OF BATTERY ELECTRIC VEHICLES AVAILABLE IN 2018 IN THE DIFFERENT VEHICLE CLASSES

Vehicle classes	**Battery capacity [kWh]**	**Specific consumption e_{BEV} [kWh/100km]**	**Range [km]**
Small cars	28.1	18.5	150
Medium cars	34.5	19.3	180
Executive cars	92.0	24.0	380
Transporters	36.6	23.6	155

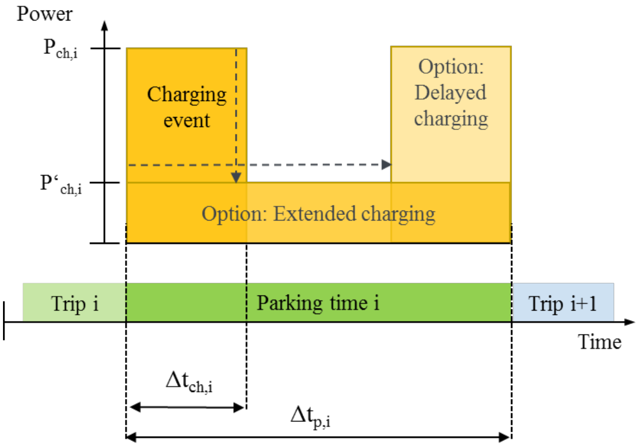

Figure 3. Time flexibility of the charging process: Charging time and charging power could be varied within the parking time. If parking time is greater than charging time (TF > 1), time flexibility is given and the charging event could be delayed. If the charging time is extended to the parking time (TF = 1), there is no time flexibility left.

It is assumed, that charging only takes place at the company for parking times greater than 1 h. Otherwise the tours are merged together. As shown in Figure 3 it is assumed that the charging process begins immediately after end time of a round trip (which is also the start time of the following parking time). The end time of the parking time marks the exit condition for the charging period (which vice versa corresponds to the start time of the next round trip). For charging common AC charging points (mode 1 – mode 3) are used including charging powers of 2.3 kW, 3.7 kW, 11 kW, 22 kW or 43 kW. A simplified rectangular charging profile is assumed. Possible time extensions, due to a lower charging current, is therefore not taken into account. That means the maximal rechargeable energy amount can be calculated by using the selected charging power P_{ch} multiplied by the available charging time Δt_p (equal to the parking time).

To calculate the consumed energy during a round trip the driven distances is multiplied by the specific consumption of the BEV. If the consumed energy exceeds the battery capacity of the BEV, it could not be used for the round trip (without intermediate charging). It is assumed that after each round trip the consumed energy has to be recharged fully for the next trip even if it is unnecessary for the next trip.

For both, consumed energy and available energy amount, the relative unit 'depth of discharge (DOD)' will be used to compare the results with regard to the vehicles classes. $DOD_{RT\ i}$ is the ratio of consumed energy $E_{consumed,RT\ i}$ of the i^th round trip in relation to the nominal energy content E_{BEV} of the battery.

$$DOD_{RT\ i} = \frac{E_{consumed,RT\ i}}{E_{BEV}}$$

$$E_{consumed,RT\ i} = \sum_{j=1}^{n} S_{RT\ i,j} * e_{BEV}$$

$$E_{ch\ potential,\ RT\ i} = \left[P_{ch,i} * \Delta t_{p,i}\right]_0^{E_{BEV}}$$

where

- $S_{RT\ i,j}$ is the travelled distance for the j^th leg of a total of n legs of the i^th round trip.
- e_{BEV} is the specific consumption of the used BEV (TABLE *I)*
- $E_{ch\ potential,\ RT\ i}$ is the potential energy, which can be recharged during the total parking time $\Delta t_{p,i}$ after the i^th round trip with charging power $P_{ch,i}$

C. *Flexibility at charging events*

Flexibility means that the framework conditions could be varied without changing the required output according to Rehfeld [16]. In our case this means that a full recharge of the consumed energy takes place within the parking time, but the charging power and the needed charging time (within the parking time) could vary. As a result, the potential of time flexibility at the charging process is gained.

In this paper, the time flexibility is defined as ratio between the required charging time to recharge the consumed energy of the previous round trip and the available charging time, or rather the parking time as shown in following formula. This definition is related to the work of Gerritsma [10]

$$TF_i = \frac{\Delta t_{p,i}}{\Delta t_{ch,i}} \qquad with \qquad \Delta t_{ch,i} = \frac{E_{consumed,RT\ i}}{P_{ch,i}}$$

where

- TF_i is the flexibility with regards to time for the charging after the i^th round trip
- $\Delta t_{p,i}$ is the parking time available after the i^th RT
- $\Delta t_{ch,i}$ is the necessary charging time, assuming the consumed energy of the i^th RT is recharged with power $P_{ch,i}$

If the ratio is equal to 1, then available and required charging time match for the selected charging power. If the ratio is larger than one, more than the required time for charging is available and could be shifted within the time. This means e.g. for the ratio equal to 2, the period of charging could be shifted once completely. If the ratio is below one, the BEV cannot be recharged fully with the assumed charging power before starting the next round trip. Thus, it would be necessary to use a higher charging power to fully recharge the BEV.

III. RESULTS

First, the possibility of a transformation from ICEs to BEVs will be discussed. Later on, the result regarding the time flexibility of the charging events will be shown.

A. *Transformation from ICE to BEV regarding to the driving behavior in economic sectors*

Figure 4 shows the distribution of round trips terminating at the company during weekdays and weekend. At the weekend many fewer, tours and those only within a few sectors are completed, for example in sector C (yellow).

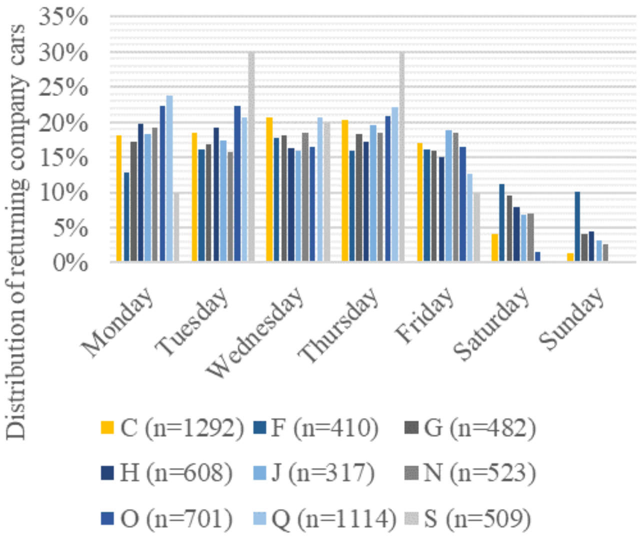

Figure 4. Distribution of company cars returning at the company from a round trip regarding to the REM 2030 data base. Most round trips terminate during week, but some during the weekend.

Regarding parking and driving time, the monitoring data validates that parking time is much longer than driving times per day. This is true for all sectors apart from sector H (transport and logistics). In sector C the overall parking time is more than four times longer than the driving time each day (cf. Figure 5). Furthermore, the average driving distance is less than 150 km per round trip for all cars (yellow bar in Figure 6). Hence, this driving distance does not reach any ranges of the BEV given in TABLE I for all vehicle classes. Even small cars match the requirements, although they are mostly used for shorter distances. But at the same time their working radius is nearly as small as the radius of all cars (30 km). It could be concluded that in case of need the trip planning could be adjusted to recharge the BEVs at the company more often.

For a more detailed analysis of each individual tour of sector C, all tours are distributed per hour over the timeline of one day, see in Figure 7. The tours terminate mainly during the day at the company. Most cars arrive during the morning hours (peak between 7:00 h and 9:00 h), then the amount of arrivals is distributed evenly throughout the day but decreases until 18:00h, after which it drops down. Hence, the distribution could trace the daily working time within the sector C. Assuming all ICEs had been replaced by BEVs, Figure 7 also considers an analysis of how much battery capacity would have been used for the average distance of the tours of each time slot. The DOD at arrival at the company has its highest values during the late working hours (e.g. when returning the car after a long round trip) but also during the early morning hours. The latter could mean the cars weren't returned after a business tour the day before or that these cars are used for commuting purposes.

The distribution of DODs at the end of the tours are arranged in Figure 8 as histogram. Over 70% of all tours would require less than 1/3 of the battery capacity. Furthermore, nearly 90% of all tours could be made by battery

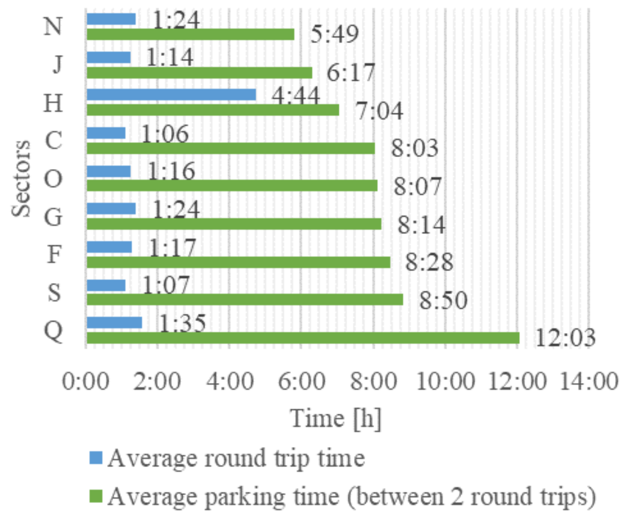

Figure 5. Monitored driving pattern in economic sector on average levels: In all sectors parking time exceeds the driving time (for round trips), most often for serval times, only exception is sector H.

electric vehicle already existing on the market. Only for the remaining 10% of the tours would an interim recharge during the tour or an ICE be needed. The distribution is similar for all classes of vehicles.

B. Flexibility of charging for commercial BEVs

The ratio between parking time and required time for recharging *TF* has been introduced previously as an indicator, whether charging at a given power level enables recharging within the parking time ($TF \geqslant 1$) or not ($TF < 1$). With $TF > 1$ for a given charging power, there is a degree of 'time flexibility' with respect to the time window used for charging.

Figure 9 provides sorted plots of the ratio *TF* for all 1292 round trips of sector C in the analyzed database and for charge powers of 2.3, 3.7, 11, 22 and 43 kW of charge power respectively. First, we focus on the plot of ratio *TF* for 2.3 kW of charge power. For this case the green line shows that the parking time after 40% of the round trips is at least 5 times longer than required for recharging. As the DOD at return of many trips are low, the required charging power is only

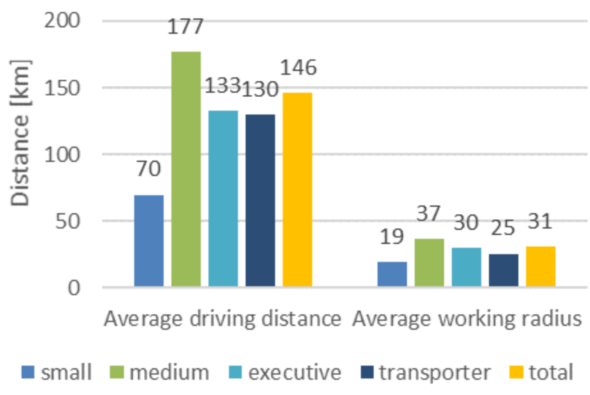

Figure 6. Driving distance and maximal working radius of each round trip in sector C for the used vehicle classes

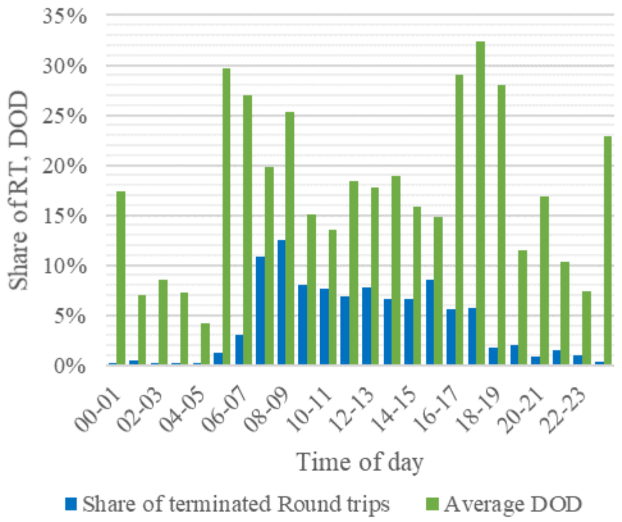

Figure 7. Distribution of returns after round trip with plot of the mean value of DOD due to driven round trips since last charging event

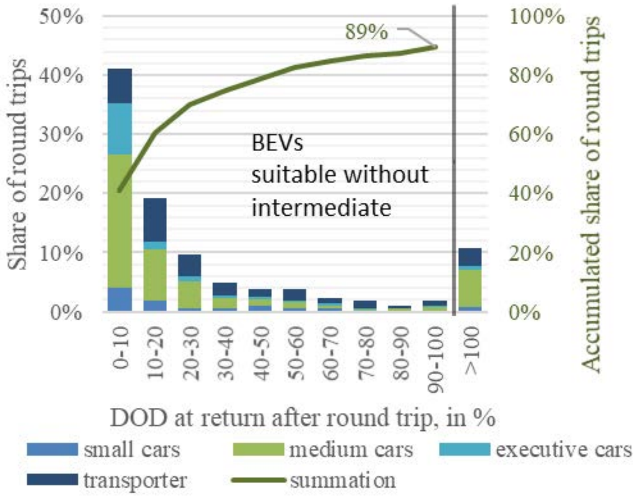

Figure 8. Depth of Discharge (DOD) at return after round trip in sector C

0.18 kW on average for this first 40% of the round trips. For additional 20% of the round trips, the parking time is 5 to 1.5 times longer than the time needed for recharging. If every car is provided 2.3 kW for recharging, 70% of the vehicles can be fully recharged during the parking time following their round trip and return to the company base with 2.3 kW (average charging power 0.58 kW). The remaining round trips need higher charging power. The average charging power as well as the required power for the share of round trips is given in TABLE II.

The dotted blue line displays the charge power (right axis) plotted against the share of round trips that can be charged during the parking time for this charge power. It is a result of interpolating the 5 values of charge powers and share of vehicles at the crossing point of the 5 sorted TF plots with the TF = 1 line. While a charge power of 2.3 kW for every vehicle allows 70 % of the round trips to be recharged during subsequent parking, a charge power of 11 kW (brown line) allows 85 % of round trips to be recharged. However, 10 % of round trips are beyond the battery capacity and therefore no time of recharging is given.

This particular case of required charging time equal to parking time (TF =1) is also shown for all sectors in Figure 10. The plots for each sector look similar, except for sector H, the transport sector. Also, the plot of all tours together (red dashed line 'average without sector H') is nearly the same than the one for sector C (yellow line). A charging power of 2.3 kW is sufficient to cover between 50 % (sector N) and 83 % (sector Q) of all tours with a mean value of 70 %. For 11 kW the rechargeable share of tours varies between 81 % and 85 % with an average of 88%. For sector H with its longer traveling distances and shorter parking times compared to the other sectors, more than 11 kW charging power is needed to cover more than 50% of all tours.

As shown for sector C, there could be a charging pattern with high simultaneity, e.g. a lot cars return to the company in the morning hours. In this period, charging power of the charging points adds up and could lead to a peak load exceeding the physical or contractual limits regarding to the grid connection. Taking economic aspects into account the higher peak loads and/ or grid reinforcements could lead to a lot more extra costs for the companies. Therefore, an intelligent charging management to control the charging power dynamically and adapt the time for charging could be of interest. This charge management could also cater for single needs of high power charging or unexpected events. Also an intelligent charging management opens the opportunity to interact with the local grid operator to charge in a grid friendly manner.

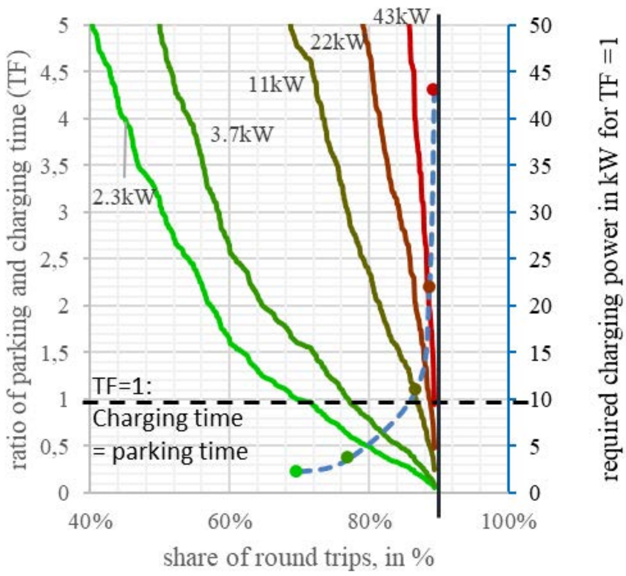

Figure 9. *Sorted Plot of the ratio (TF) between parking time and required time for recharging for all 1292 round trips of sector C. The charge power is given as parameter. A ratio TF ≥ 1 means fully rechargeable within parking time*

TABLE II. CHARGING POWER REQUIERED TO RECHARGE AFTER RETURN FOR DIFFERENT NUMBERS OF ROUND TRIPS IN SECTOR C

Number of round trips	Average Charging Power, in kW	Peak charging power, in kW
40%	0.11	0.45
70%	0.37	2.31
85%	0.71	7.85
89.3% (limit)	0.86	45.36

Taking all economic sectors into account 4 out of 5 company cars could be replaced by BEVs assuming that companies will use charging infrastructure with 11 kW due to reasonable prices and small efforts. Regarding the driving distances and the available charging time, 89 % of all 6332 round trips would have been possible with BEVs available on the market today without intermediate charging (91% for the sectors in Figure 10 without sector H)).

IV. SUMMARY

The aim of the paper was to analyze the potentials for the usability of battery electric vehicles (BEVs) in the economic sector. Monitoring data from company cars were used to determine how many of the 6332 clustered business round trips could be made with BEVs within the different economic sectors. Furthermore, it was investigated which value of charging power is required to recharge during parking time at the company base. Flexibility with respect to time was considered.

As a result, 89% of all 6300 tours analyzed would have been possible with BEVs available on the market today without intermediate charging. The remaining 10% of round trips are beyond the battery capacity and the BEV would need to recharge during the round trip. Restricting the charging power to 11 kW, 4 out of 5 company cars (ICEs) could easily be replaced by BEVs.

For the manufacturing sector C, which was analyzed in more depth, less than a 1/3 of the battery capacity is used for over 70% of all round trips. The parking time exceeds in all sectors the driving time. If every car is provided 2.3 kW for recharging, 70% of the round trips can be fully recharged during the subsequent parking time. The average power level needed to recharge those cars during subsequent parking is a mere 0.37 kW.

A higher charging power of 11 kW is sufficient to fully recharge more than 85% of all round trips not only for the manufacturing sector but also of all sectors excluding sector ‘Transports and Logistics’. For the latter sector 11 kW covers over 50 % of its trips.

If BEVs are used for 70% of all trips and recharged with 11 kW, the parking time is 4.5 times longer than the time needed for recharging. The charging event could be postponed in a grid-friendly manner, but requires an intelligent charging management to control the charging power dynamically and

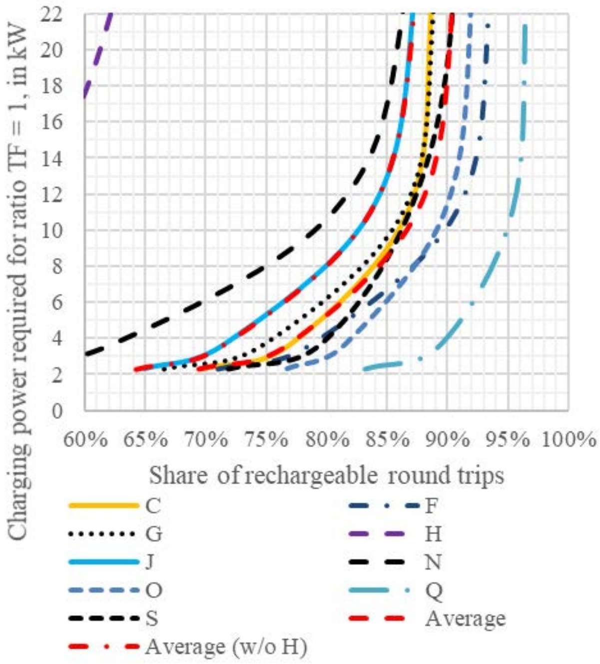

Figure 10. *Share of fully rechargeable round trips after return for all economic sectors and the required charging power for the specific case that charging time matches parking time (TF =1)*

adapt the time for charging. This charge management could also cater for single needs of high power charging or unexpected events.

This paper assumes that BEVs are fully recharged every time after return from the round trip at the company. But as seen in the results a full charged battery isn’t necessary for most trips. Also, destination charging could be done during the round trips. That’s why further investigations should be made to analyze the change of time flexibility at the charging process if this options are taken into account.

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Appendix

Table III. Indexes of different economic sectors corresonding to the Statistical Classification of Economic Activities in the European Community (NACE), REV. 2 [17]

Index	Driving profiles	Economic sector
A	-	Agriculture, forestry and fishing
B	-	Mining and quarrying
C	133 (21%)	Manufacturing
D	17 (3%)	Electricity, gas, steam and air con-ditioning supply
E	7 (1%)	Water supply; sewerage, waste management and remediation activities
F	41 (7%)	Construction
G	58 (9%)	Wholesale and retail trade; repair of motor vehicles and motorcycle
H	53 (8%)	Transportation and storage
I	-	Accommodation and food service activities
J	22 (3%)	Information and communication activities
K	6 (1%)	Financial and insurance activities
L	2 (<1%)	Real estate activities
M	10 (2%)	Professional, scientific and technical activities
N	46 (7%)	Administrative and support service activities
O	94 (15%)	Public Administration and Defence; Compulsory Social Security
P	-	Education
Q	87 (14%)	Human health and social work activities
R	-	Arts, entertainment and recreation activities
S	54 (9%)	Other service activities
T	-	Activities of Households as Employers; Undifferentiate Goods and Services Producing Activities of Households for Own Use
U	-	Activities of Extraterritorial Organisations and Bodies